J. Perinat. Med.
2 (1974) 268

Computed dip-parameters derived from digitized FHR-curves III. The valuating parameter

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Received February 26, 1974. Accepted July 1, 1974.

Some authors [1] have shown that in groups with normal and pathological neonatal courses, the frequency distributions of certain descriptive parameters of dips are different from each other. However, these differences are not large enough that they can serve as the basis for an evaluation of the state of the fetus. **The purpose of this work is to provide a new parameter which allows a better discrimination between normal and pathological states of the newborn.** This means that **the new parameter** — beyond a purely visual description of a dip — **should be the measure of the severity of a dip.** In order to arrive at a parameter which evaluates the dip as opposed to one that describes it, the following have to be considered:

1. **It is not sufficient to observe just one descriptive parameter, several descriptive parameters of a dip must be considered simultaneously.**
2. **The parameters have to be weighted different significances.**
3. **The dip cannot be considered by itself, but its past history should be considered in the two parts of this work.**

1 Evaluating parameter without considering past events

In order to satisfy the first two demands the statistical method of discriminant analysis can be used [4, 5].

Curriculum vitae

Dr. HARALD SCHMIDT *was born in 1939 and studied physics from 1959 to 1965 at the University of Hamburg. He obtained his doctorate in 1969 working in experimental and nuclear physics. As the head of the institutional electronics laboratory he has been occupied with the design of electronic measuring circuitry and with problems of hardware and software in the use of computers in data processing. Since 1971 he has been in perinatology research at the Department of Obstetrics and Gynecology at the University of Düsseldorf. His principal areas of investigation are the analysis of biological signals, in particular, the investigation of fetal heart frequency.*

1.1 Method

If two parameters (e. g. area, lag time) are known from each variable to be evaluated (e. g. a dip) one may use, besides a one-dimensional plot of the frequencies of the two parameters, a two-dimensional plot of the frequencies of the two parameters, a two-dimensional plot whereby the parameters are plotted as coordinates X and Y for each event so that each event is represented by a plot in a plane.

In Fig. 1 (from [5]) events from two different groups are indicated by two different symbols.

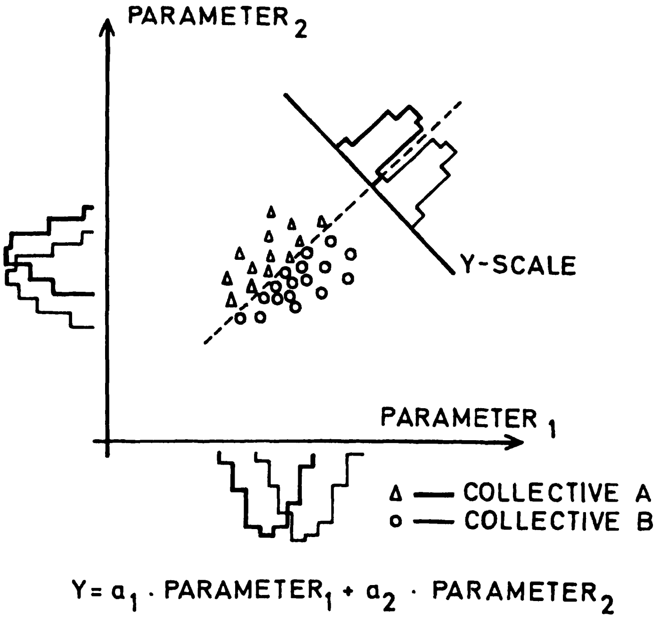


Fig. 1. Discriminant analysis.

From this two-dimensional plot of the events, a one-dimensional frequency distribution of parameters 1 or 2 is obtained by projecting the plot on the axes of the coordinates. In the illustrated case the frequency distributions from the samples A and B are different. However, the distributions are not completely separated from each other, but they overlap in part. This is true for both projections.

The two-dimensional plot demonstrates that the scattergrams of both samples are completely separated. If, instead of projecting on an axis of the coordinate system, one projects on a vertical of the separating line, a complete separation between the samples is obtained. This indicates that the numerical value of the projection on this line can be used as a discriminant of belonging to one sample or the other. The projection onto a line is calculated from the formula quoted in Fig. 1 where the values for a_1 and a_2 depend on the position of the line.

Discriminant analysis is used for calculating the line for optimally separating the collectives. For this purpose it is necessary to indicate for each event, besides its characteristics, to which sample

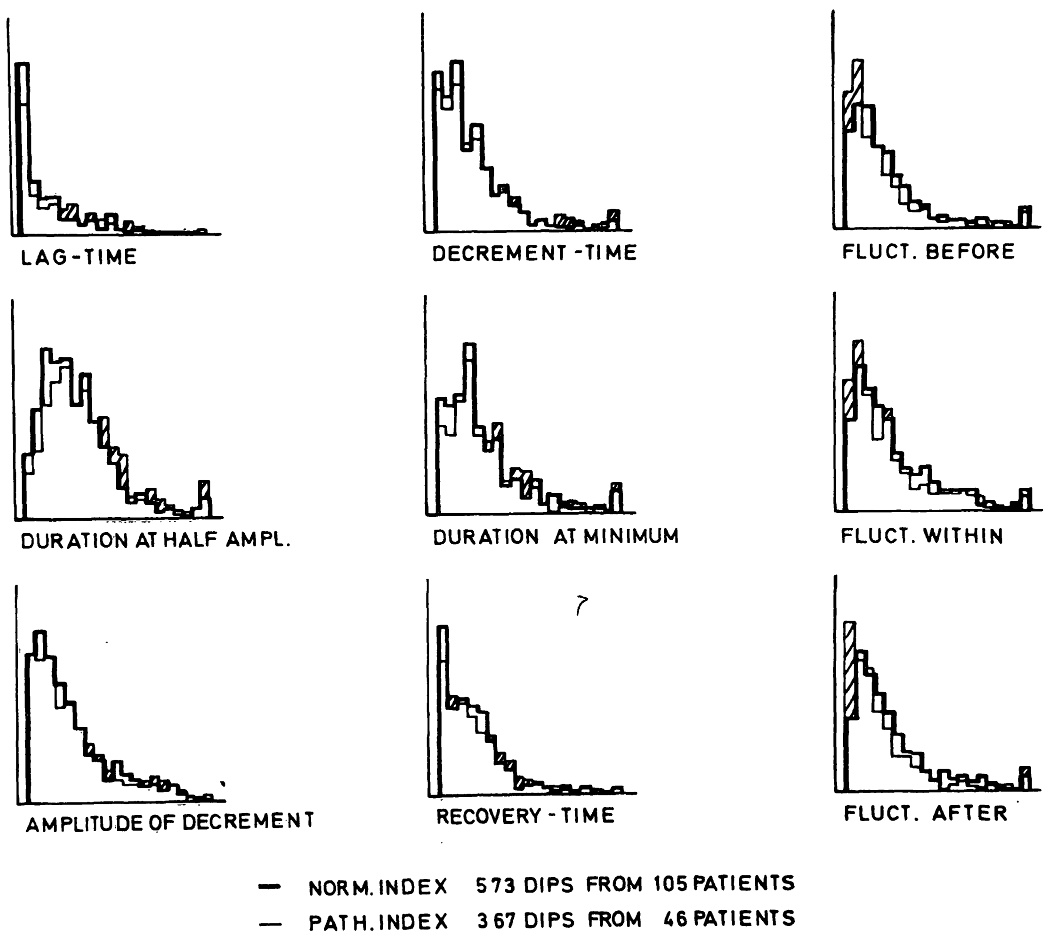


Fig. 2.
Frequency distributions of dip parameters from groups with normal and pathological newborn courses (all dips).

it belongs. By applying discriminat analysis, values are obtained by which the parameters are to be multiplied, i. e. the weight of the single parameters has been obtained.

What has been shown here for an illustrative case, i. e. for 2 parameters, can easily be extended to 3, 4, 5 . . ., n parameters. The theoretical derivation of the formulas of discriminant analysis assumes a normal distribution of the values for the characteristics. KOLLER [3] has shown, however, that the formulas can have good results even with marked deviations from a normal distribution.

Discriminant analysis has been used for the descriptive parameters of a dip. Definition and derivation of these parameters have been described in part I of this work. The data from part II are the basis for our examination.

1.2 Results

It is not appropriate to admit parameters for discriminant analysis which are logically or arithmetically dependent on others, as, for instance, the two sides of a square. For this reason we have only admitted those descriptive parameters of a dip of which a certain independence can be assumed. The discriminant analysis was frequently repeated with different parameters until the weights of all the descriptive parameters were found.

Fig. 2 depicts the frequency distribution of those parameters which were found to be the most sensitive for indicating the difference between the groups. In the following illustrations the distributions for the collective with a normal neonatal course are indicated in bold lines while those for the collective with pathological newborn states are indicated by a thin line. Fig. 2 illustrates that a **separation between groups with pathological and normal newborn index is uncertain from using single parameters even though there are marked differences in several, i. e. the fluctuation and duration at half amplitude.**

From these parameters, the rates of the single parameters indicated in Fig. 3 are obtained by reiterative use of discriminant analysis, and thus, the new evaluating parameter Y. In the upper

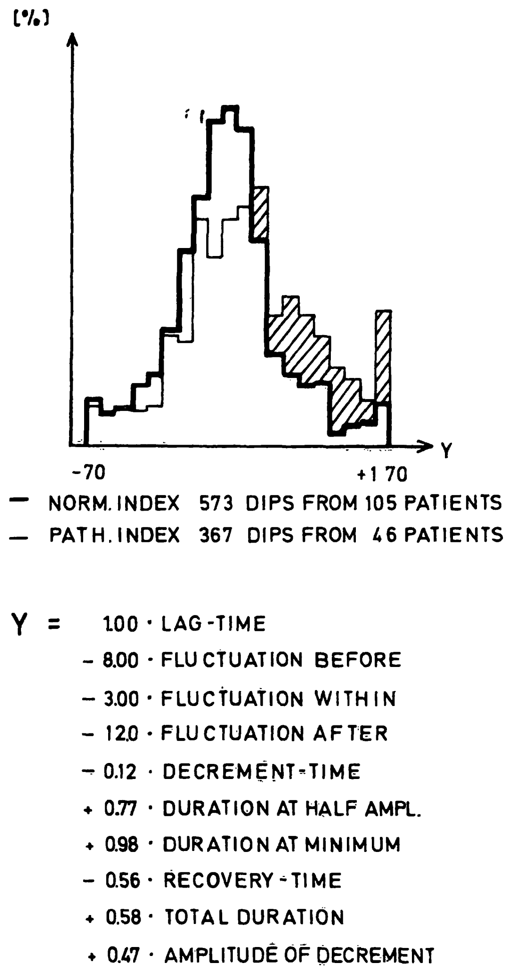


Fig. 3. Result of discriminant analysis (all dips)

half of Fig. 3 the frequency distributions of the evaluating parameter Y are depicted.

It is seen that for the group with pathological newborn index, higher values for Y occur more frequently than in the group with normal newborn index. The difference of the distributions of the parameter of Y between the two groups is significant at the 0.001 level in the U-test and the KOLOMOGOROFF-SMIRNOW tests; it is markedly greater for each single descriptive parameter. It is understandable that the value of parameter Y does not create a complete separation between the two groups because:

1. From each patient the entire time of CTG recording during birth has been used. Thus the group with a pathological newborn index contains periods and therefore dips which occur before an incipient fetal distress or, in other words, at which time fetus was still well.

2. Another — even if purely theoretical — reason can be sought in that the pathological state of the newborn is only represented in dips which are caused by certain causes, e. g. not in those occasioned by head compression.

These dips, which more correctly are part of the other group explain the incomplete separation.
It has been tested whether the result of the discriminant analysis is indeed correlated with the state of the newborn or whether it occurred by chance. For this purpose all dips were pooled and assigned randomly to a group. Discriminant analysis was then applied to the dips of these groups and it was seen that the weights of the parameters thus derived were, in part, meaningless and that the differences of the parameters Y between the two random groups were much smaller than in Fig. 3. It was about as large as for the single parameters.
Without data processing the calculation of the projection Y was very cumbersome because of the many factors entering in its determination. Therefore, we have limited ourselves to just some parameters and have used only those which can be determined more easily and are more meaningful.
Furthermore, only dips with a lag time of over 20 seconds were admitted since only type II dips are generally considered pathological. Fig. 4 demonstrates the frequency distribution of these parameters. It can be seen from these distributions that **even in these dips with a lag time of over 20 seconds, single parameters do not allow an evaluation of the fetal state.**
Fig. 5 contains the results of the discriminant analysis with these dips and these parameters. The distribution of the evaluating parameter Y

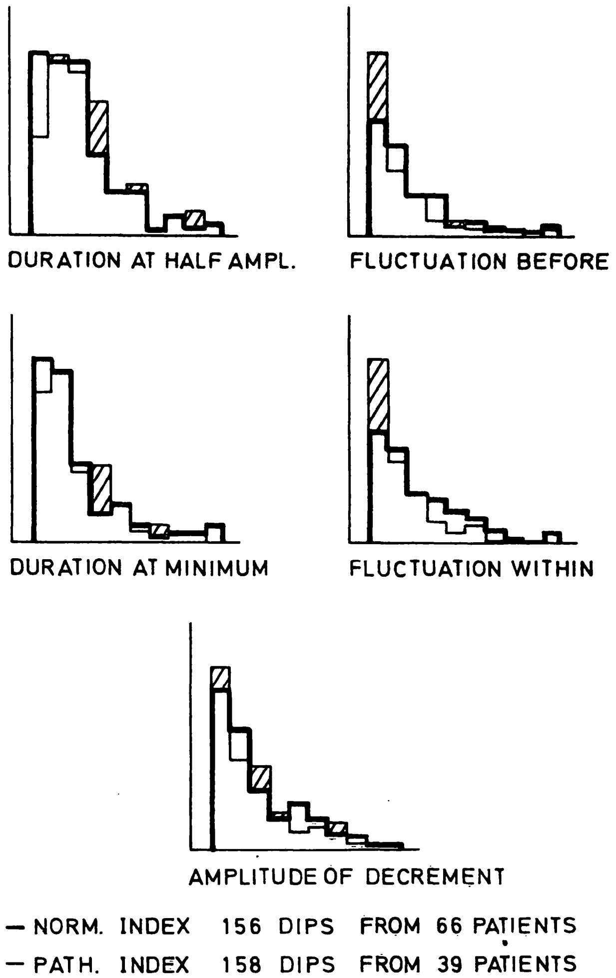
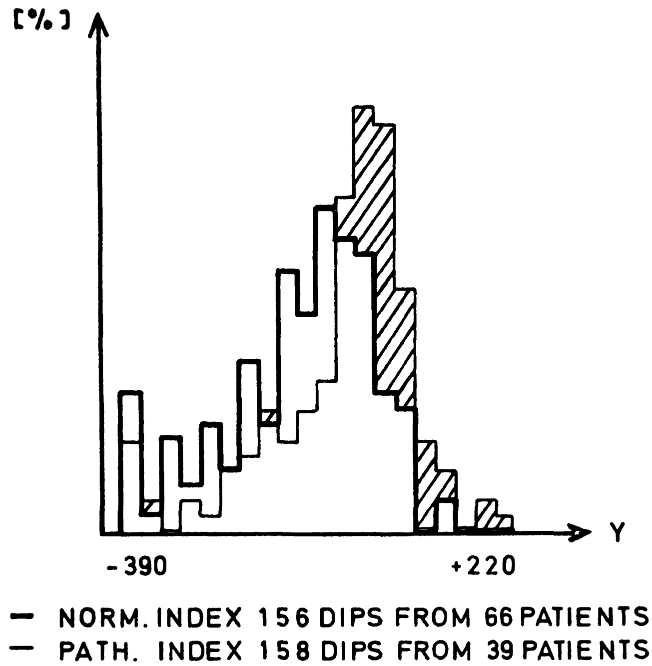


Fig. 4. Frequency distributions of dip parameters from groups with normal and pathological newborn status (dips with lag time of over 20 seconds).



Y = - 44.0 · FLUCTUATION BEFORE
- 32.0 · FLUCTUATION WITHIN
+ 1.00 · DURATION AT MINIMUM
+ 1.00 · DURATION AT HALF AMPL.
+ 3.07 · AMPLITUDE OF DECREMENT

Fig. 5. Result of discriminant analysis (dips with lag time of over 20 seconds).

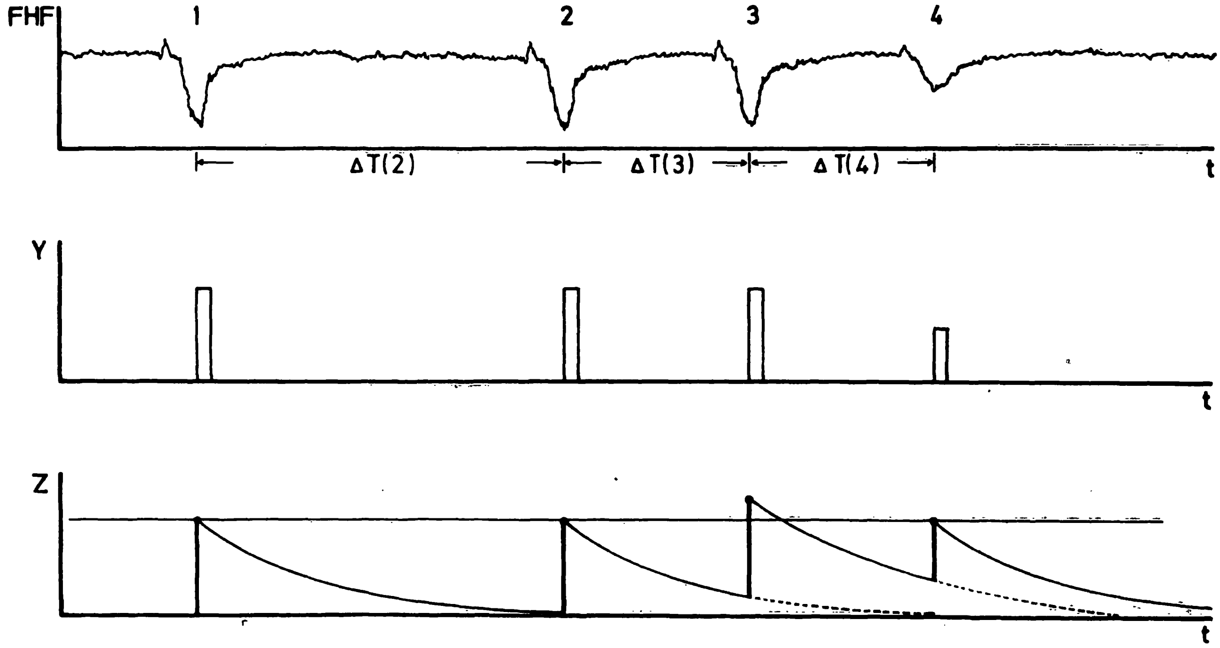
indicates that a good discrimination between the groups is possible. However, the limitations named in Fig. 3 must be observed here as well. In the lower portion of the illustration the parameters and their weights are indicated which serve for calculating parameter Y. It is easily seen that these weights calculated from the discriminant analysis of the dip parameters and the assignation to a group coincide in regard to their sign with clinical experiences:
The broader and deeper the dip, the larger the value of the evaluating parameter Y, i. e. the further one gets to the area in which the dips of the groups with pathological newborn courses predominate. From this dip the fluctuation, i. e. the measure of the oscillation of the original FHR around an average FHR is subtracted. If the FHR has still many short-time changes more is subtracted than in the case of a loss of short-time variations and smaller values of Y are obtained, i. e. one gets into the area where the dips of a normal group predominate.

2 Evaluating parameters with consideration of past events

Section A showed a possibility for solving demands 1 and 2 referred to in the introduction. This portion will point out a method which allows the **consideration of preceding dips and their temporal sequence.** We used and modified a suggestion by JUNGE [2] and applied it to the evaluating parameter.

2.1 Method

In Fig. 6 which explains this method, the first three dips (first row) are different only by the time interval between the dips. According to the formula described in section A, identical values for parameter Y (see second row) are obtained for them. The time sequence is now considered so that the value of this parameter is decreased exponentially and thus is being "forgotten" slowly (third row). Thus the time between the first and second dip is large enough so that the



$$Y(i) = \sum_k a_k X_k(i)$$

$$Z(i) = Y(i) + Z(i-1)\,e^{-\frac{\Delta T(i)}{\tau}}$$

$X_k(i)$ = PARAMETER k FROM DIP i
a_k = WEIGHT OF PARAMETER k
ΔT = TIME BETWEEN DIP (i) AND (i-1)
τ = CONSTANT OF TIME

Fig. 6. Explanation for discriminant analysis with and without considerations of past events (dips with lag time of over 20 seconds).

value of the first dip is completely forgotten by the second dip, while this is not the case by the third dip. The parameter Z is calculated from the formula in Fig. 6. t is a measure for the time in which preceding dips have been considered. The time constant was determined with a program from the same data as in Figs. 4 and 5.

2.2 Results

It was seen that the separation between the groups improves with the increase of t. Above t = 450 seconds (i. e. within this time preceding dips are considered according to the above formula) no further improvement of the separation of the collectives could be achieved. This value, t = 450 seconds, has been accepted as a limit.

In Fig. 7 the frequency distribution of the evaluating parameter with and without consideration of the preceding events are compared with each other. It is seen that **by considering preceding dips a further improvement of the discrimination between groups of normal and pathological newborn courses can be accomplished.**

In conclusion we wish to stress that these data, of course, provide only hypotheses of new evaluating dip-parameters which have to be tested with new data.

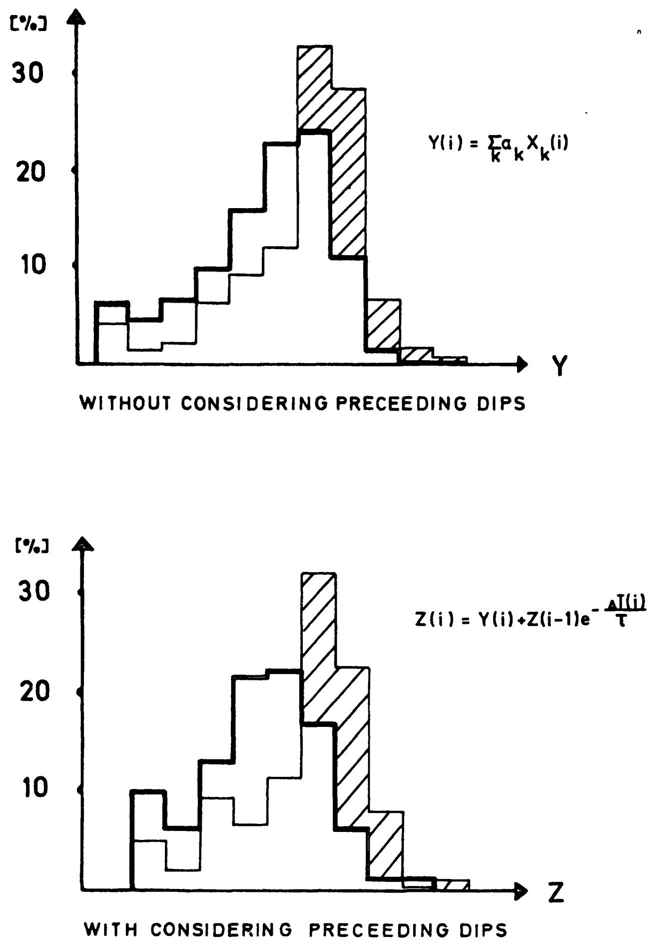


Fig. 7. The frequency distribution of the evaluating parameter with and without consideration of the preceding events.

Summary

The descriptive parameters of 473 and 376 dips respectively from groups with normal and pathological newborn courses were utilized for this investigation.

Since a single parameter descriptive of the dip does not allow a reliable evaluation of the fetal state, we attempted to derive a parameter which evaluates the dip which statisfies the following demands:

1. **Several descriptive parameters are considered simultaneously.**
2. **The descriptive parameters are weighted differently as to their power of discrimination.**
3. **Preceeding dips and their time sequences are considered.**

The first two demands were fulfilled by the use of discriminant analysis **(Fig. 1)** which resulted by a linear combination of the descriptive parameters in an evaluating parameter. The parameter Y thus derived allows a good discrimination between the groups, utilizing a total of 10 descriptive parameters per dip **(Figs. 2 and 3).** By restricting the use of the dips to those with a lag time of over 20 seconds and using only 5 parameters per dip the discrimination was improved **(Figs. 4 and 5).**

The time sequence of preceding dips **(Fig. 6)** was considered under the assumption that the valuating parameter Y was forgotten only slowly (or decreased exponentially). The sum of the remainder of the preceding dip and the evaluating parameter Y resulted in a parameter Z **(Fig. 7)** in which the past history of the dip is considered. The time constant, which is a measure for the time within the preceding dips must be considered, was determined as t = 450 seconds. The frequency distribution of the parameter Z show a marked difference between the groups with normal and pathological newborn courses respectively.

Keywords: Asphyxia index, decelerations, digitized data, electronic data processing, fetus, frequency distributions, parameters of deceleration.

Zusammenfassung

Computer-Auswertung von Dip-Parametern aus digitalisierten fetalen Herzfrequenzkurven
III. Bewertende Parameter
Die beschreibenden Dip-Parameter von 573 Dips (367 Dips) der Kollektive mit normalem bzw. pathologischem Neugeborenenzustand standen dieser Untersuchung zur Verfügung.
Da ein einzelner, den Dip beschreibender Parameter kaum eine sichere Beurteilung des fetalen Zustandes erlaubt, ist der Versuch unternommen worden, den Dip bewertende Parameter abzuleiten, die folgenden Forderungen genügen:

1. **Es werden mehrere beschreibende Parameter gleichzeitig beachtet.**
2. **Diese beschreibenden Parameter werden infolge ihrer verschiedenen Aussagekraft unterschiedlich gewichtet.**
3. **Es werden die vorangegangenen Dips und deren zeitliche Folge berücksichtigt.**

Die ersten beiden Forderungen konnten mittels der Diskriminanz-Analyse **(Fig.1)** erfüllt werden, die durch Liniarkombination der beschreibenden Parameter zu einem bewertenden Parameter führte. Der hieraus ermittelte Parameter Y erlaubt eine gute Unterscheidung zwischen den Kollektiven, wobei insgesamt 10 beschreibende Parameter pro Dip berücksichtigt werden **(Figs. 2—3)**. Durch die Einschränkung auf Dips mit einer lag-time größer als 20 sek. und die Beschränkung auf 5 Parameter pro Dip konnte die Unterscheidung zwischen den Kollektiven verbessert werden **(Figs. 4—5)**.
Die zeitliche Folge vorangegangener Dips **(Fig. 6)** wurde unter der Annahme berücksichtigt, daß dieser bewertende Parameter Y nur langsam vergessen (exponentiell abgebaut) wird. Die Summe aus dem verbleibenden Rest des vorangegangenen Dips und dem bewertenden Parameter Y führt zu einem Parameter Z **(Fig. 7)**, in dem die Vorgeschichte des Dips berücksichtigt worden ist. Die Zeitkonstante, die ein Maß für die Zeit ist, innerhalb der die vorangegangenen Dips beachtet werden müssen, wurde zu t = 450 sek. bestimmt.
Die Häufigkeitsverteilungen des Parameters Z zeigen einen deutlichen Unterschied zwischen den Kollektiven mit normalem bzw. pathologischem Neugeborenenzustand.

Schlüsselwörter: Asphyxie-Index, Dezelerationen, Dezelerations-Parameter, digitalisierte Daten, elektronische Datenverarbeitung, Fet, Häufigkeitsverteilungen.

Résumé

Les paramètres Dip computé dérivés de courbes FHR digitalisées III. Le paramètre d'évaluation
L'étude présente a porté sur les paramètres Dip descriptifs de 573 Dips (367 Dips) des groupes avec état normal ou pathologique des nouveaux-nés.
Un seul paramètre décrivant le Dip ne suffisant guère à apprécier avec certitude l'état foetal, on a essayé de dériver les paramètres évaluant le Dip sous les seules conditions suivantes:

1. **Observation simultanée de plusieurs paramètres descriptifs.**
2. **Appréciation différentielle de ces paramètres des criptifs selon la nature diverse de leurs données.**
3. **Prise en considération des Dips antérieurs et de leur ordre chronologique.**

Les deux premières conditions ont pu être remplies par l'analyse discriminante **(Fig. 1)** qui a permis d'établir un paramètre d'évaluation par combinaison linéaire des paramètres descriptifs. Le paramètre Y ainsi obtenu permet à son tour de bien distinguer les groupes où il est tenu compte au total de 10 paramètres descriptifs par Dip **(Figs. 4—5)**. En limitant les Dips à un lag-time supérieur à 20 sec et en ne dépassant pas 5 paramètres par Dip, on a pu améliorer la «discrimination» entre les groupes **(Fig. 6)**.
La série des Dips antérieurs **(Fig. 6)** a été prise en considération sous l'hypothèse que ce paramètre d'évaluation Y ne se dégrade expotentiellement qu'avec lenteur. La somme extraite du reste du Dip antérieur et du paramètre d'évaluation Y mène à un paramètre Z **(Fig. 7)** qui tient compte des antécédents du Dip. La constante de temps, qui est une mesure pour le temps et à l'intérieur de laquelle les Dips antérieurs doivent être pris en considération, a été determinée à t = 450 sec.

Les distributions de fréquence du paramètre Z montrent une nette différence entre les groupes avec état normal ou pathologique de nouveau-né.

Mots-clés: Décélérations, distributions de fréquence, données digitalisées, foetus, index d'asphyxie, paramètre de décélération, traitement électronique des données.

Acknowledgement

This work was supported by the Bureau of Research, Ministry of Science and Research, State of Northrhine-Westphalia.

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